Building An Event Generator For EIC

Tobias Toll

What's on the market?

XDVMP - A first attempt

Open Questions

To do

INT 10-3 Workshop on
Perturbative and Non-Perturbative Aspects of QCD at Collider Energies
29/9 2010

The Market ep/pp

Generator	Underlying Principle	pp	ep	Diffraction
Pythia 8	DGLAP	x		Some
Pythia 6	DGLAP	x	x	Some
HERWIG++	Ang. Ord. DGLAP	x	x	Some
SHERPA	DGLAP CKKW	x	x	
LEPTO	DGLAP		x	x (Soft)
RAPGAP	DGLAP		x	x
Ariadne	Large colour dipoles	x	x	
CASCADE	CCFM	x	x	
...				

The Market AA

Generator	Underlying Principle
EPOS (NEXUS)	Multiple Scattering in Parton Ladders
VENUS	String formation/fragmentation
HIJING	Mini-Jet Structures
UrQMD	Dense Hadronic Matter Properties
RQMD	Dense Hadronic Matter Properties
(VNI)	Hadronic Decomposition + DGLAP
MARTINI	DGLAP in a Thermal Medium
JEWEL	Jet Quenching
Q-Pythia, Q-HERWIG	Jet Quenching
...	

The Market eA

What we want

- A multi purpose generator
  - High and low Q2
  - High and low x
  - Exclusive final states
  - Diffraction
  - ...

Will probably need to be a collection of many programs collected in a package.

What we want

Plan:

To have a workshop on
a multi purpose event generator for an EIC

XDVMP

eXclusive Diffractive Vector Meson Production

http://rhig.physics.yale.edu/~ullrich/xdvmp/

XDVMP

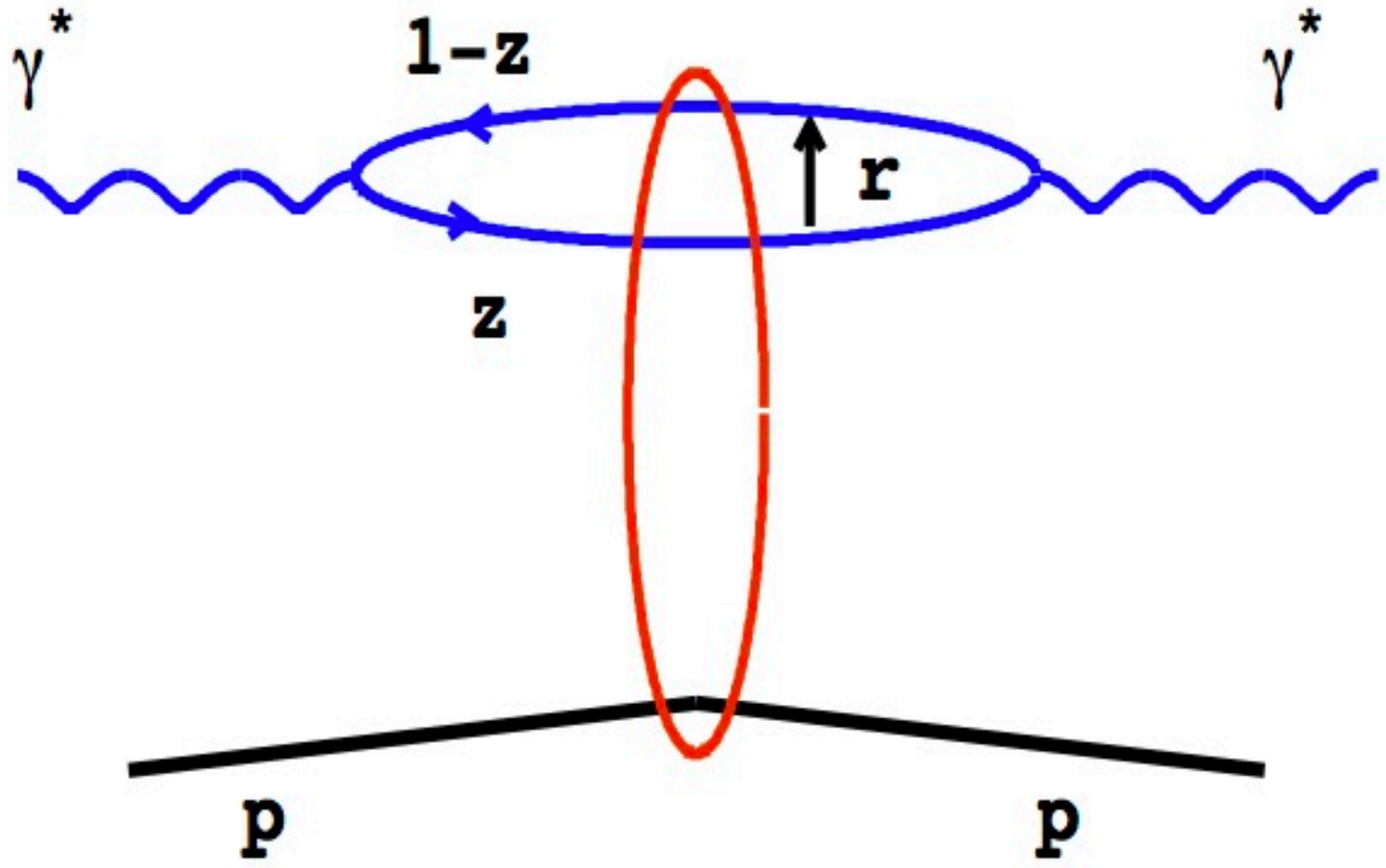
eXclusive Diffractive Vector Meson Production

Work in progress!!!

http://rhig.physics.yale.edu/~ullrich/xdvmp/

The Dipole Model

Elastic photon-proton scattering

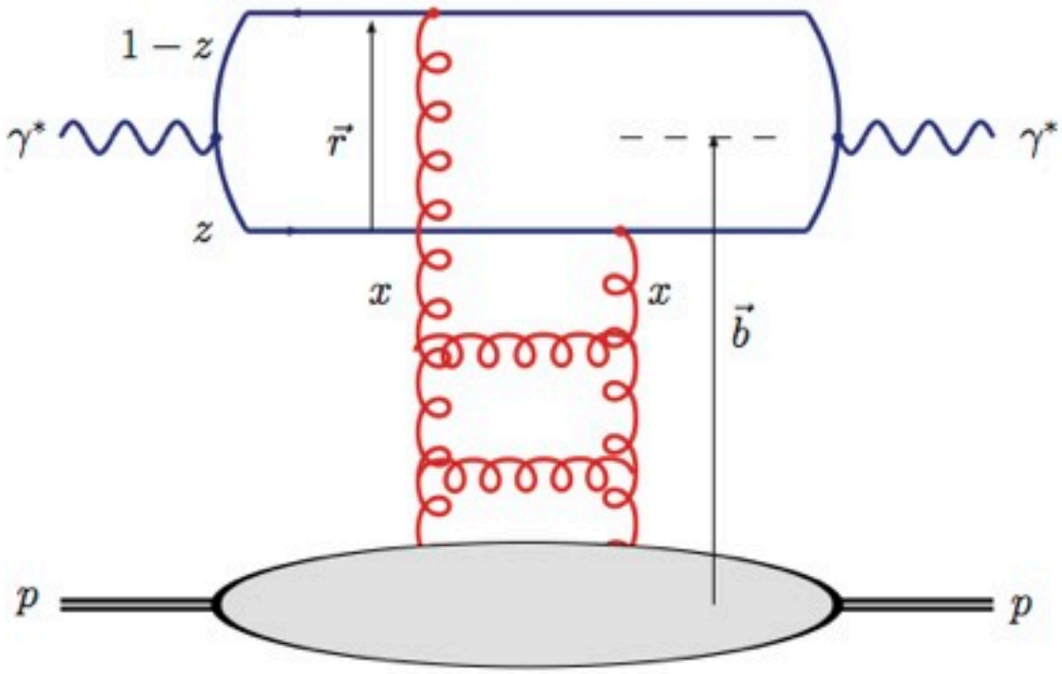


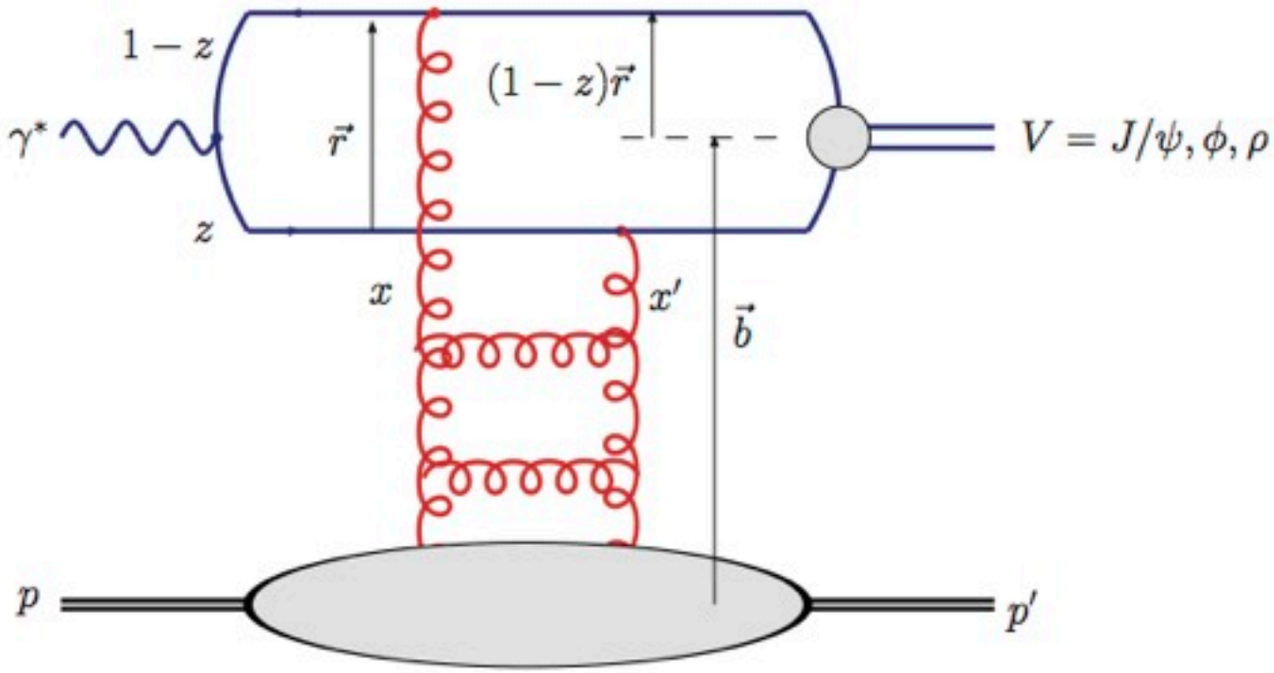
$$\mathcal{A}^{\gamma^* p}(x, Q, \Delta) =$$

$$\sum_f \sum_{h,\bar{h}} \int \mathrm{d}^2\mathbf{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} \Psi^*_{h\bar{h}}(r, z, Q) \mathcal{A}_{q\bar{q}}(x, r, \Delta) \Psi_{h\bar{h}}(r, z, Q)$$

Exclusive diffractive processes at HERA within the dipole picture, H. Kowalski, L. Motyka, G. Watt, Phys. Rev. D74, 074016, arXiv:hep-ph/0606272v2

Vector Meson Production





$$\mathcal{A}_{T,L}^{\gamma^* p \to V p}(x, Q, \Delta) =$$

$$i \int \mathrm{d}\mathbf{r} \int_0^1 \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b} (\Psi_V^* \Psi)_{T,L}(2\pi r) J_0([1-z] r\Delta)(2\pi b) J_0(b\Delta) \frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}}$$

Known from QED

Needs to be modeled

The Dipole Models

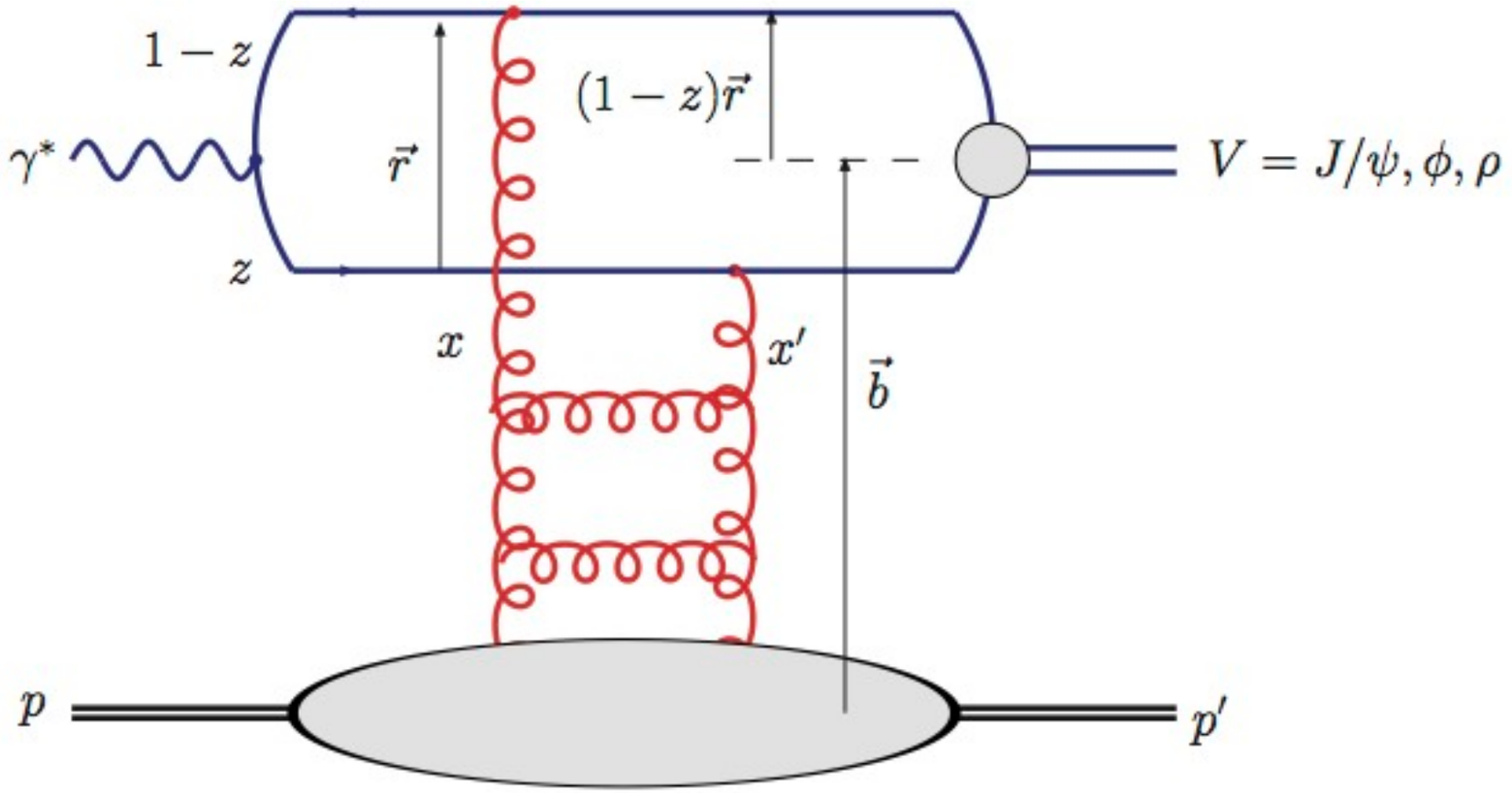
$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}}$$

Two models for the dipole cross-section implemented in XDVMP:

b-Sat

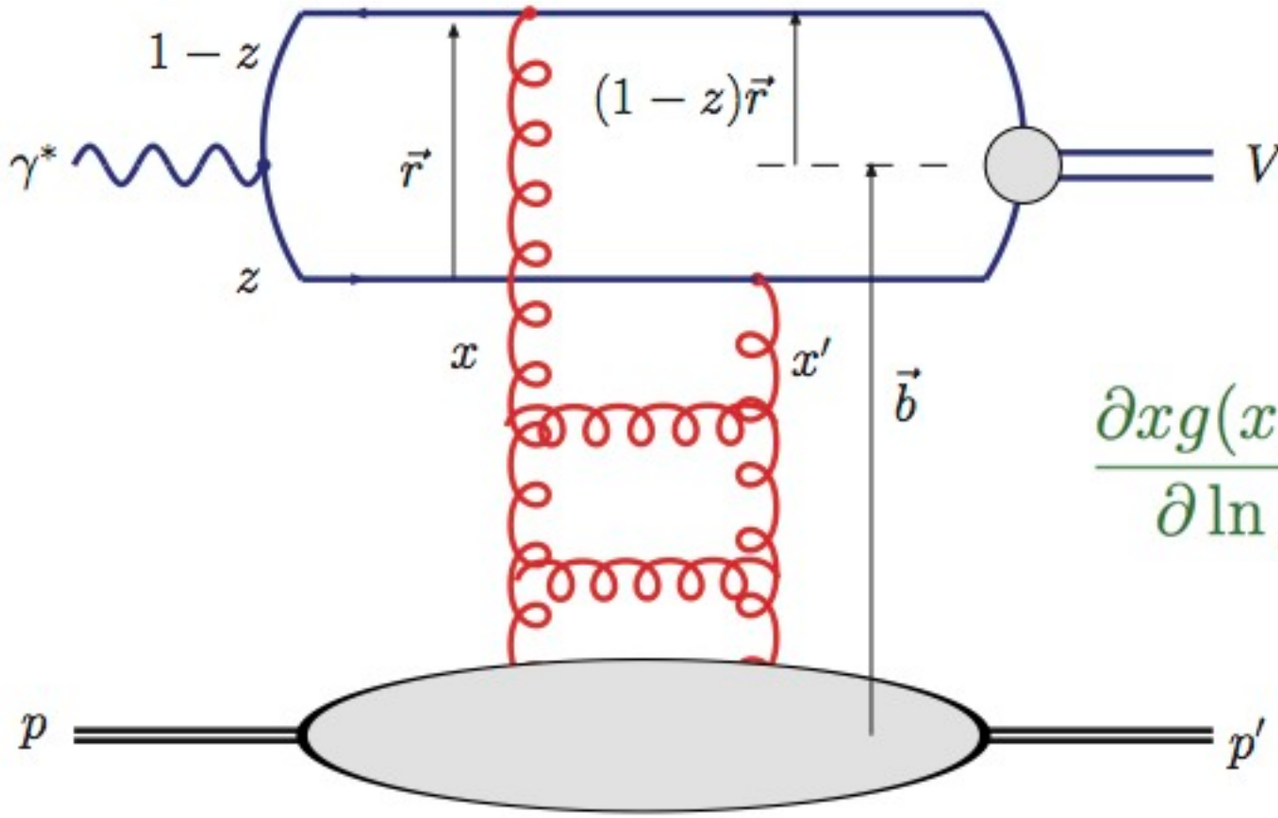
b-CGC

The b-Sat Model



$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x,\mu^2) T(b)\right)\right]$$

The b-Sat Model

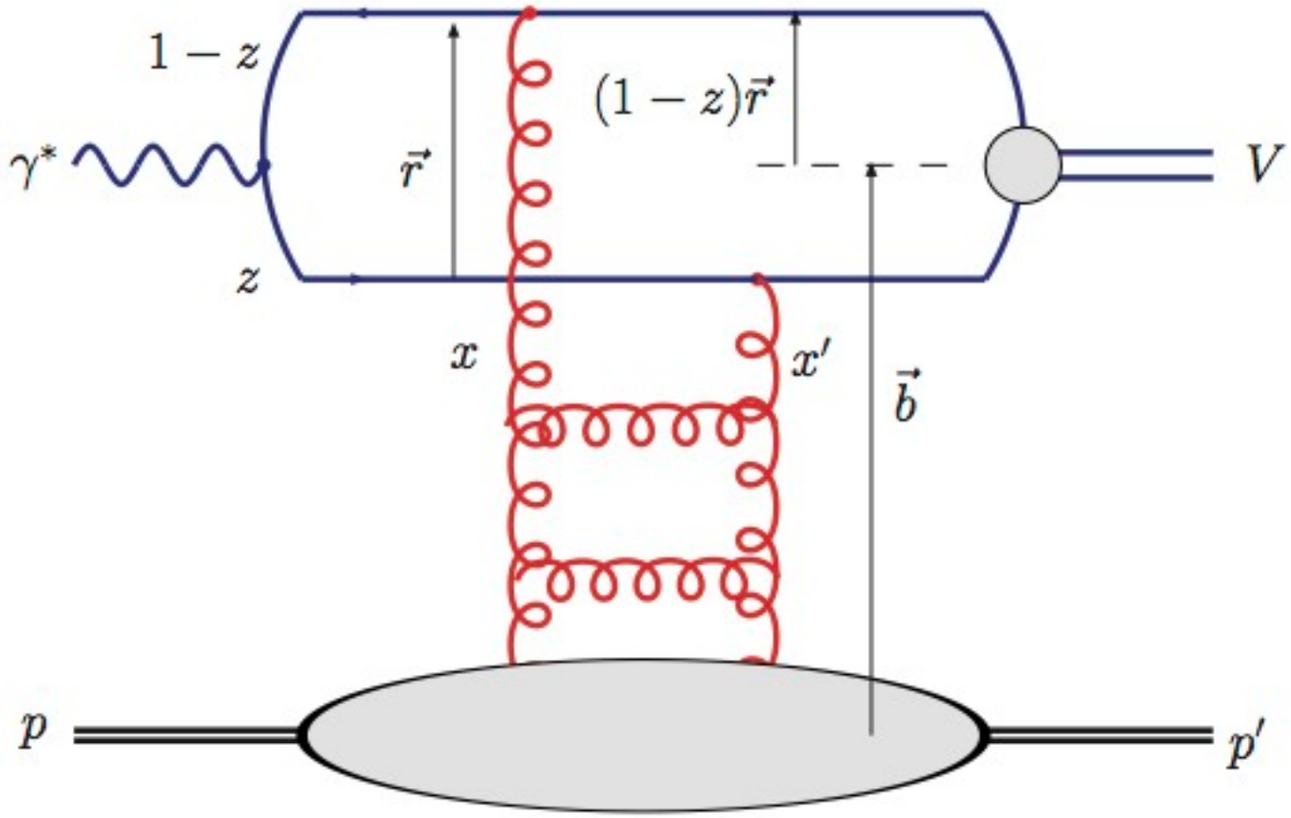


$$\frac{\partial x g(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi}\int_x^1 dz P_{gg}(z)\frac{x}{z}g\left(\frac{x}{z},\mu^2\right)$$

$$\frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}} = 2\left[1-\exp\left(-\frac{\pi^2}{2N_c}r^2\alpha_s(\mu^2)xg(x,\mu^2)T(b)\right)\right]$$

$$\mu^2 = \frac{4}{r^2}+\mu_0^2$$

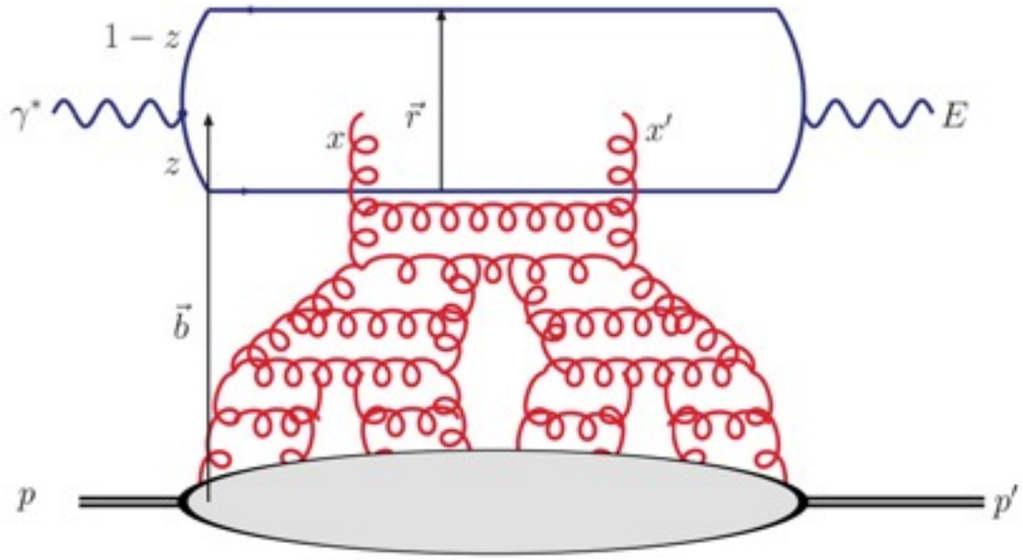
The b-Sat Model



$$T_G(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}}$$

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x,\mu^2) T(b)\right)\right]$$

The b-CGC Model



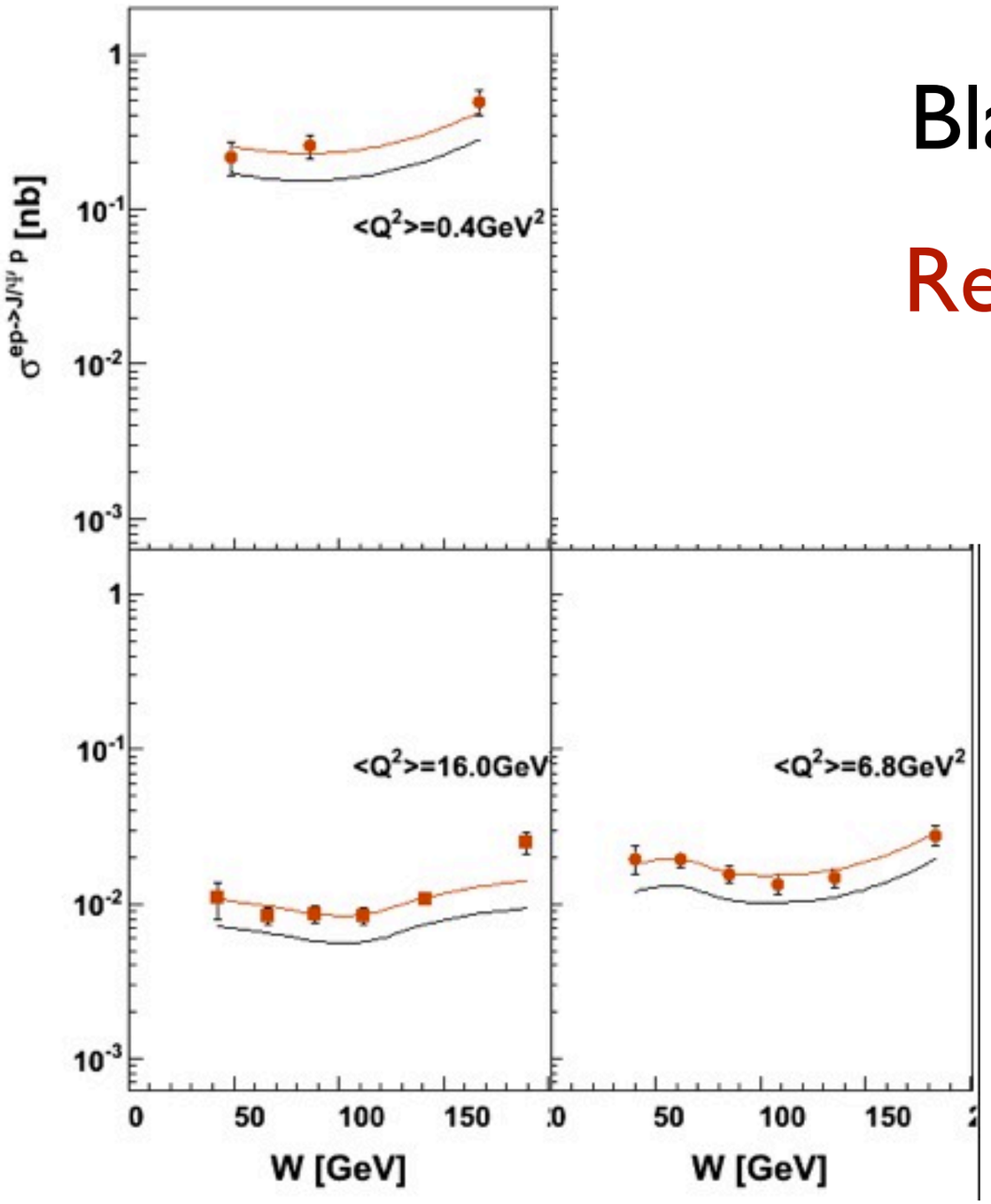
$$Y = \ln(1/x),\ \gamma_s = 0.63,\ \kappa = 9.9$$

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2 \times \begin{cases} \mathcal{N}_0 \left(\frac{rQ_s}{2}\right)^{2\left(\gamma_s + \frac{1}{\kappa\lambda Y}\ln\frac{2}{rQ_s}\right)} & rQ_s \leq 2 \\ 1 - e^{-A\ln^2(BrQ_s)} & rQ_s > 2 \end{cases}$$

$$Q_s \equiv Q_s(x,b) = \left(\frac{x_0}{x}\right)^{\lambda/2} \left[\exp\left(-\frac{b^2}{2B_{\mathrm{CGC}}}\right)\right]^{\frac{1}{2\gamma_s}}$$

First comparison with data

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695



Black Curve: XDVMP b-CGC

Red Curve: Black Curve x 1.5

Something is missing!!

Plots produced by Ramiro Debbe

Real Amplitude Corrections

So far the amplitude has been assumed to be purely imaginary.

To take the Real part of the amplitude into account it can be multiplied by a factor $(1+\beta^2)$

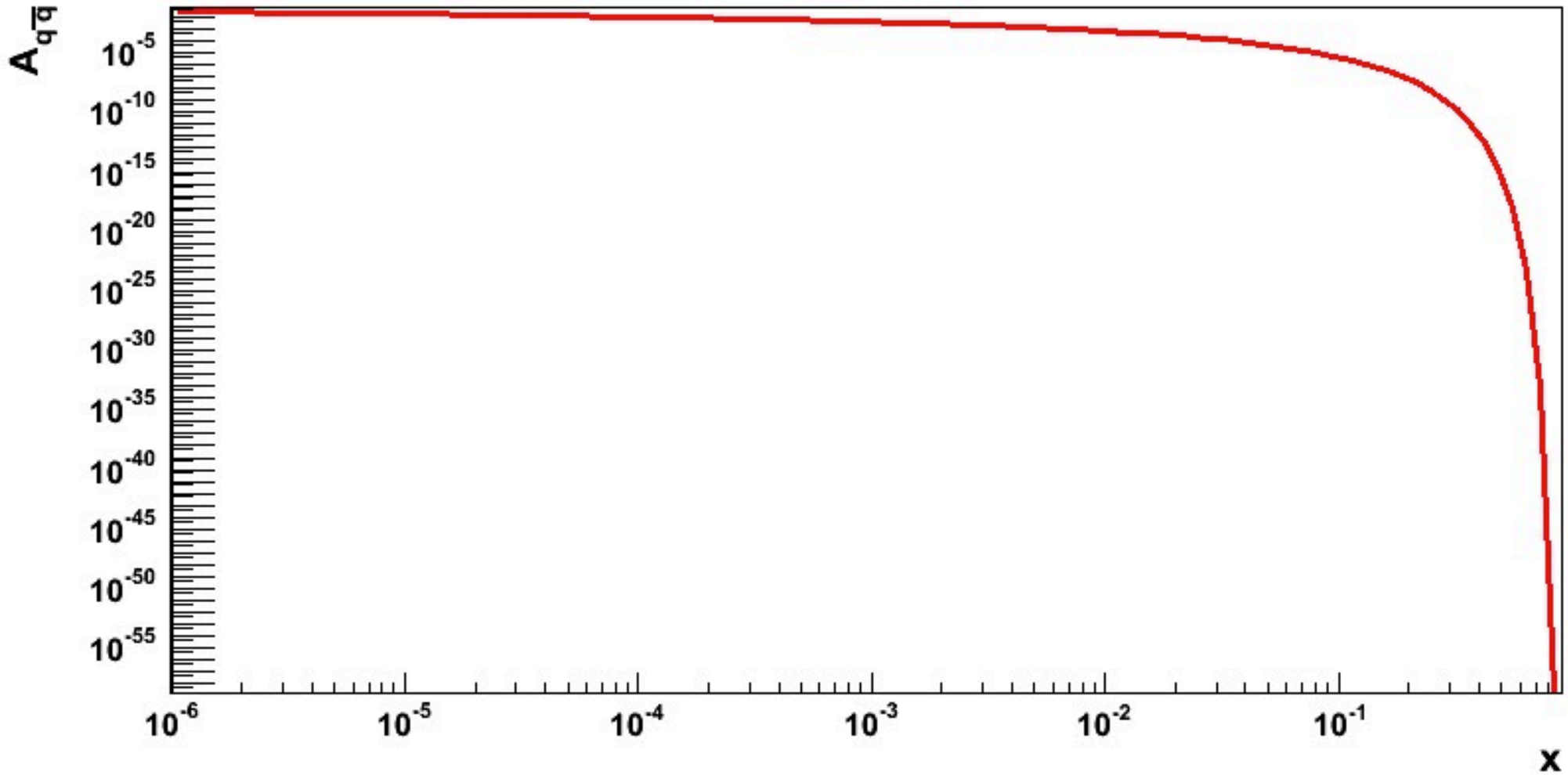
β is the ratio Real/Imaginary parts of the Amplitude:

$$\beta = \tan(\pi\lambda/2) \qquad \lambda \equiv \frac{\partial \ln\left(\mathcal{A}_{T,L}^{\gamma^* p \to Ep}\right)}{\partial \ln(1/x)}$$

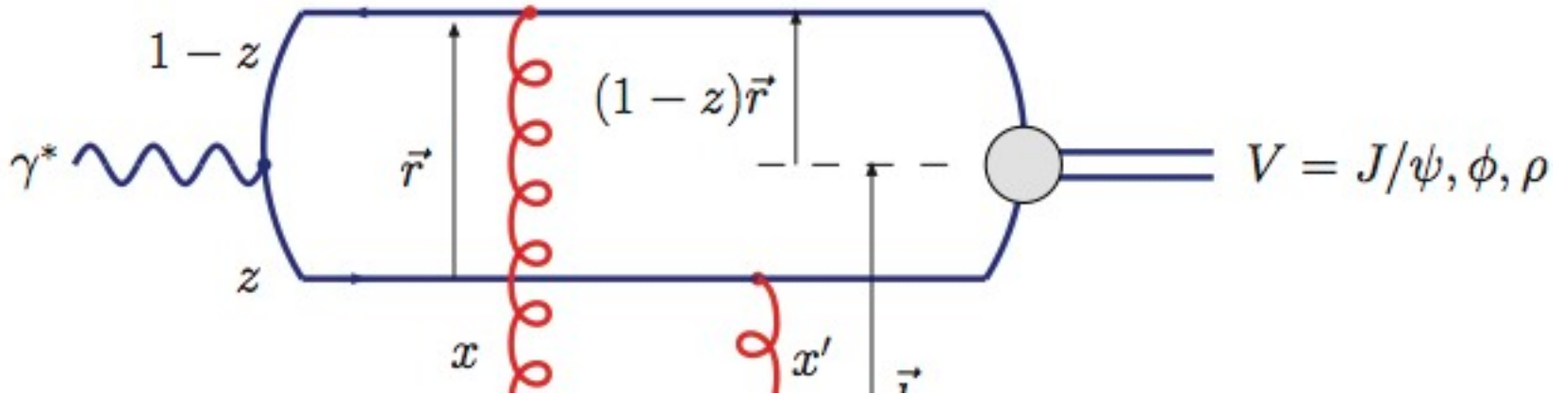
This goes bad for large $x \sim 10^{-2}$

Real Amplitude Corrections

$$\beta = \tan(\pi\lambda/2) \qquad \lambda \equiv \frac{\partial \ln\left(\mathcal{A}_{T,L}^{\gamma^* p \to Ep}\right)}{\partial \ln(1/x)}$$



Skewedness Corrections



The two gluons carry different momentum fractions

This is the Skewed effect

In leading ln(1/x) this effect disappears

It can be accounted for by a factor R_g

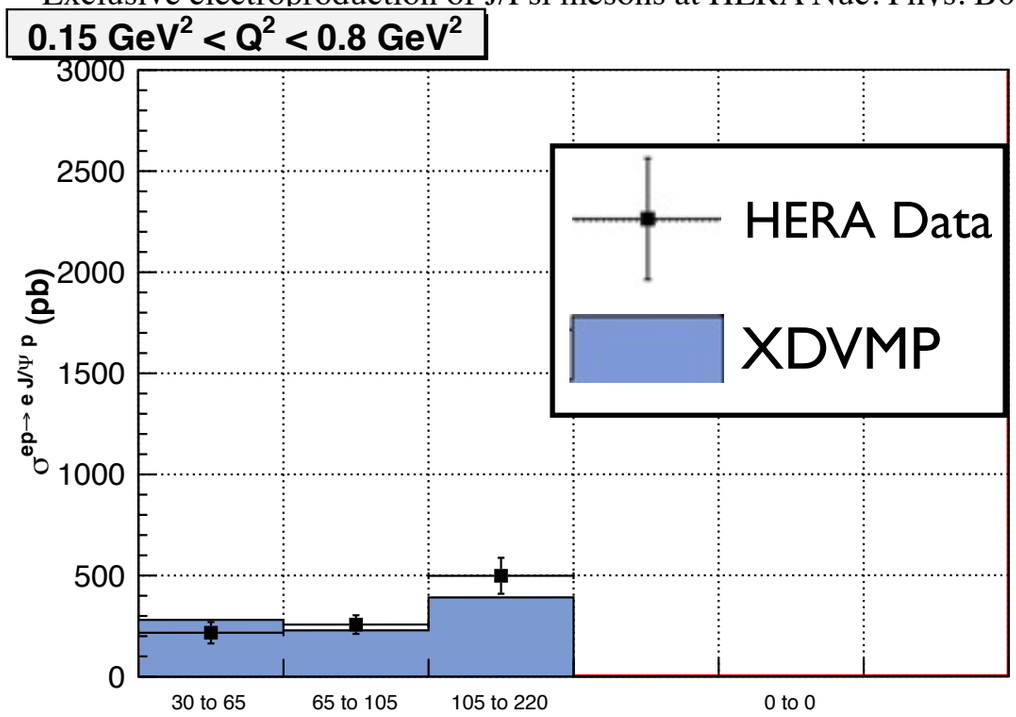
$$R_g(\lambda) = \frac{2^{2\lambda+3}}{\sqrt{\pi}} \frac{\Gamma(\lambda+5/2)}{\Gamma(\lambda+4)} \qquad \lambda \equiv \begin{cases} \dfrac{\partial[xg(x,\mu^2)]}{\partial \ln(1/x)} & \text{bSat} \\ \dfrac{\partial \ln(\mathcal{A}_{T,L}^{\gamma^* p \to Ep})}{\partial \ln(1/x)} & \text{bCGC} \end{cases}$$

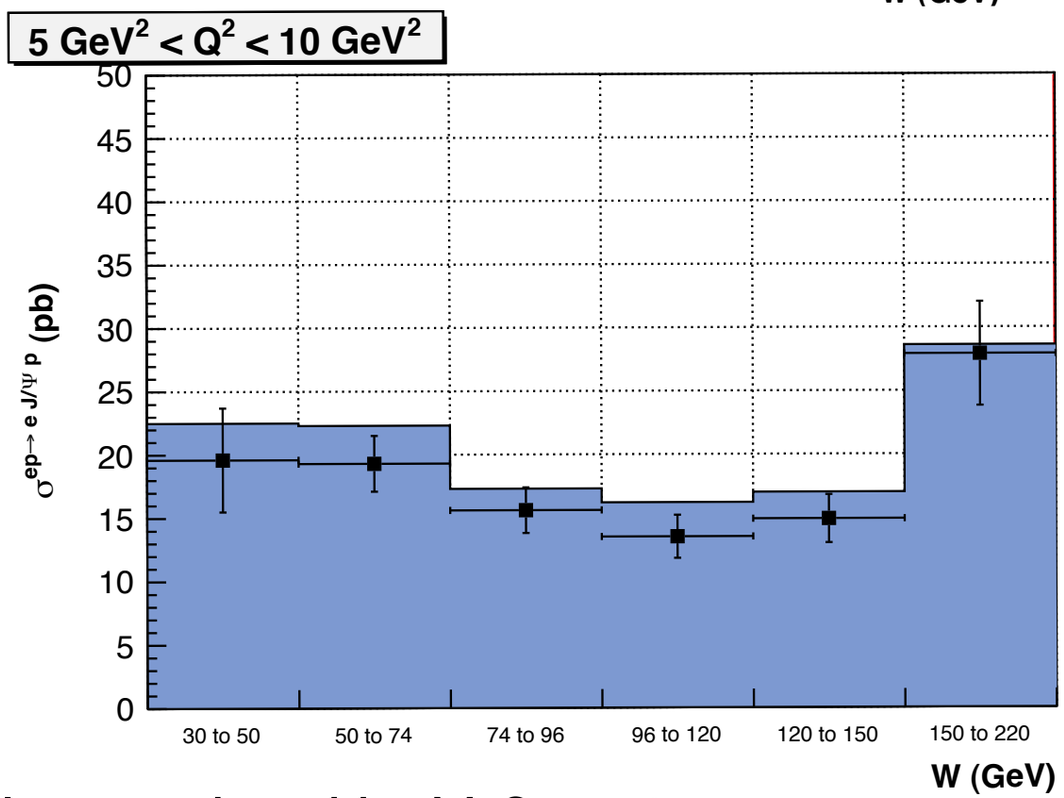
Again, this goes bad for large $x \sim 10^{-2}$!

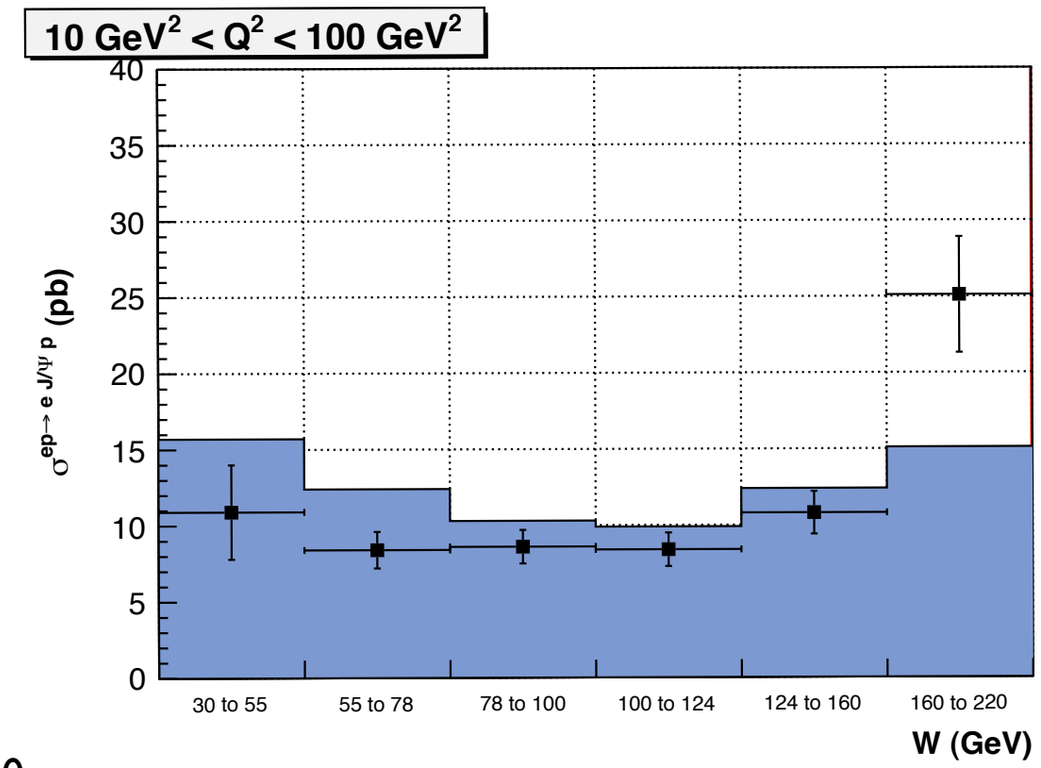
Implemented with exponential damping to control this.

J/Psi at HERA vs. b-CGC

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695





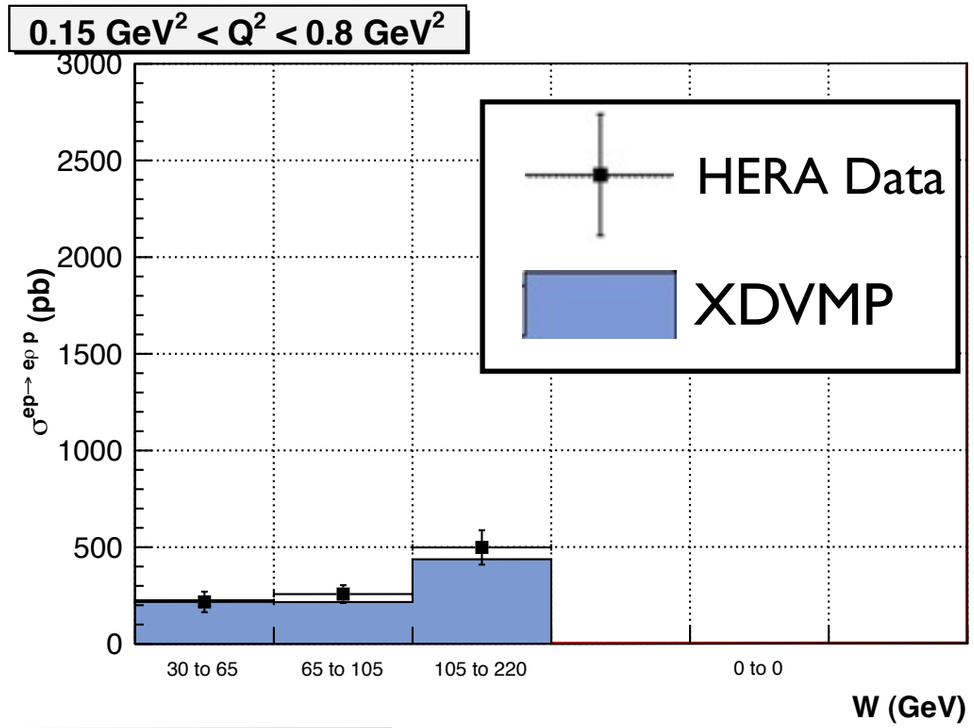


With all corrections!!

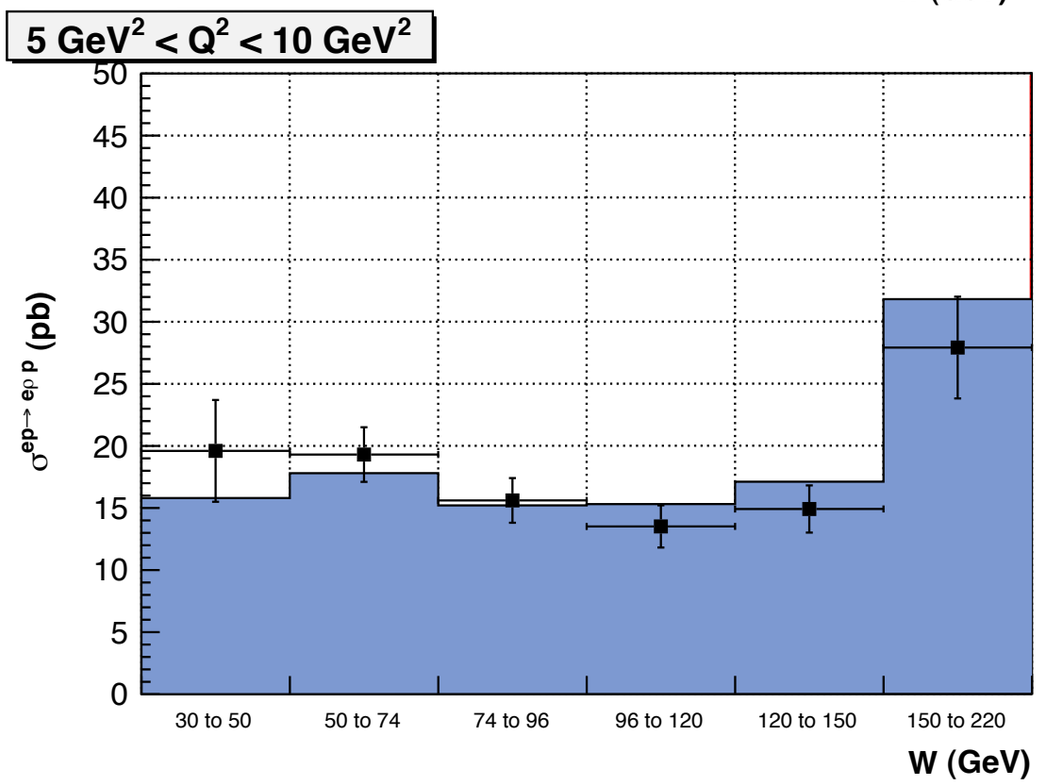
Plots produced by M. Savastio

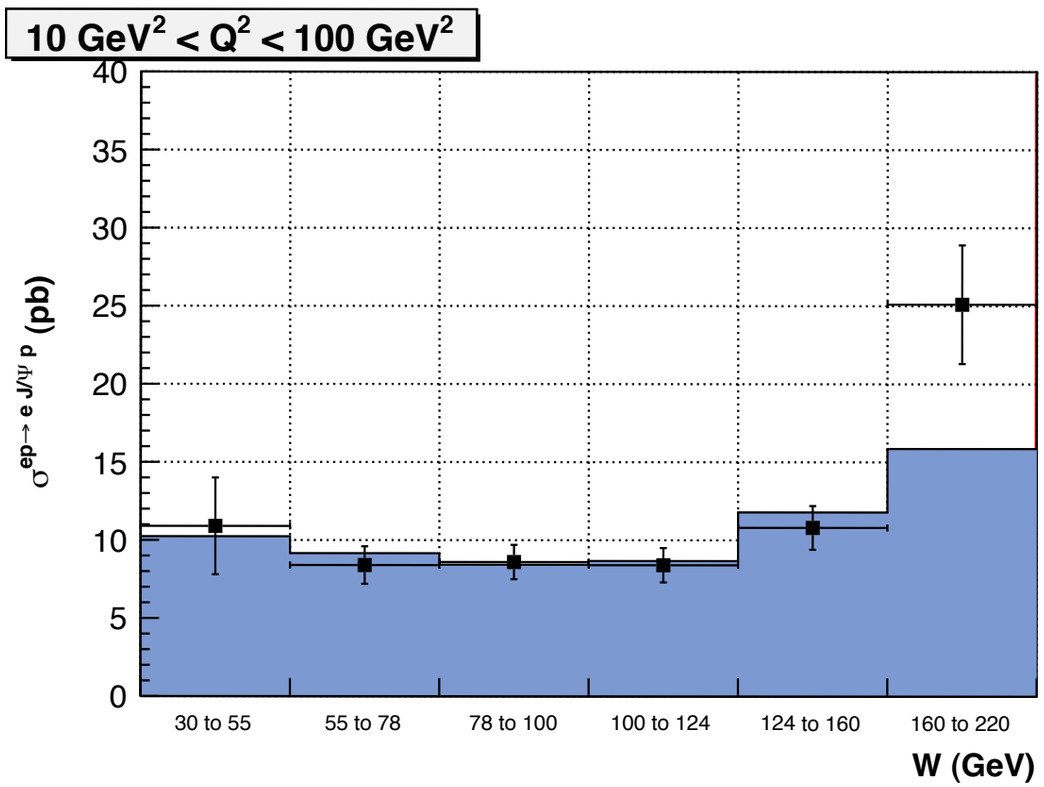
J/Psi at HERA vs. b-Sat

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695



With all corrections!!





Plots produced by M. Savastio

Going from ep to eA

ep:

$$\mathrm{Re}(S) = 1 - \mathcal{N}^{(p)}(x, r, \mathbf{b}) = 1 - \frac{1}{2}\frac{\mathrm{d}\sigma_{q\bar{q}}^{(p)}(x, r, \mathbf{b})}{\mathrm{d}^2\mathbf{b}}$$

eA:

$$1 - \mathcal{N}^{(A)} = \prod_{i=1}^{A} \left(1 - \mathcal{N}^{(p)}(x, r, |\mathbf{b} - \mathbf{b}_i|)\right)$$

Should follow the Wood-Saxon distribution

Generating a Nucleus

Generate radii according to the Wood-Saxon distribution

Generate angles

$\cos(\theta)$ uniform in [-1:1]

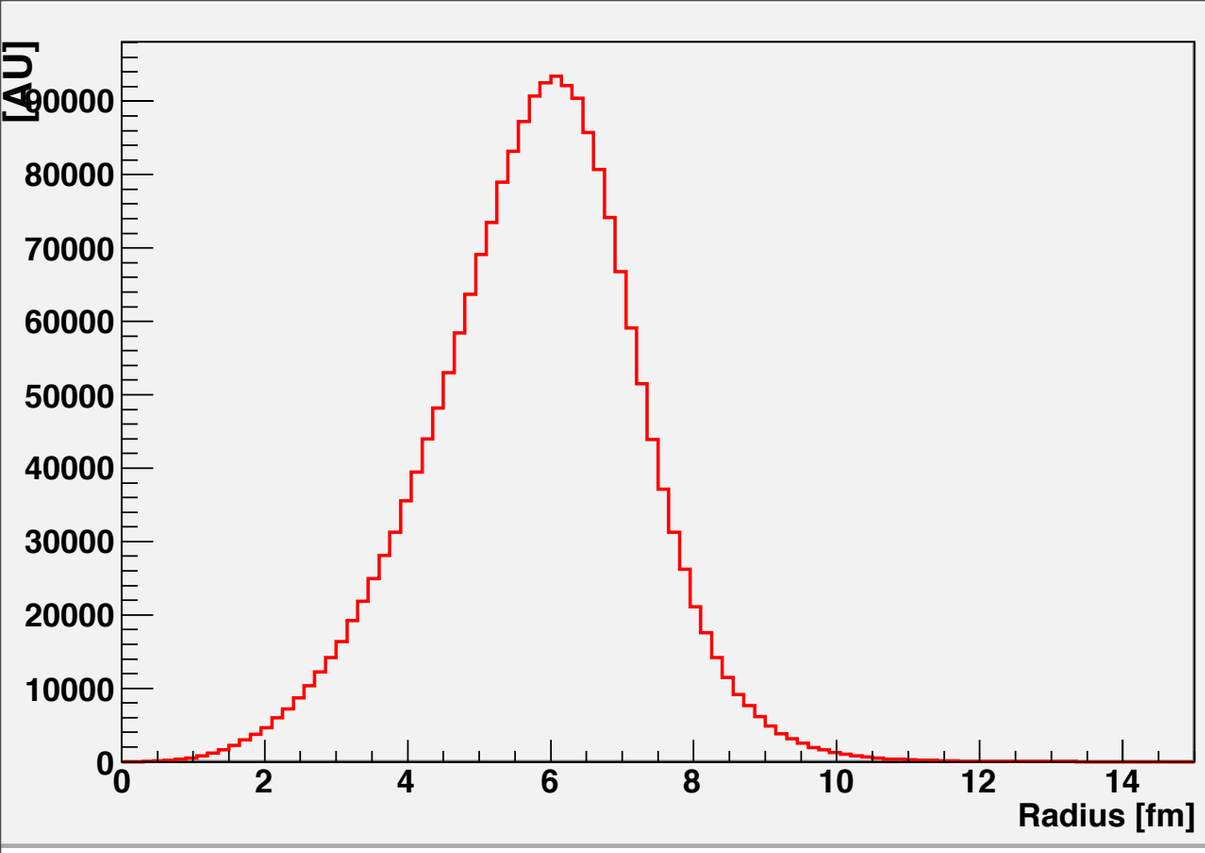
ϕ uniform in [0:2π]

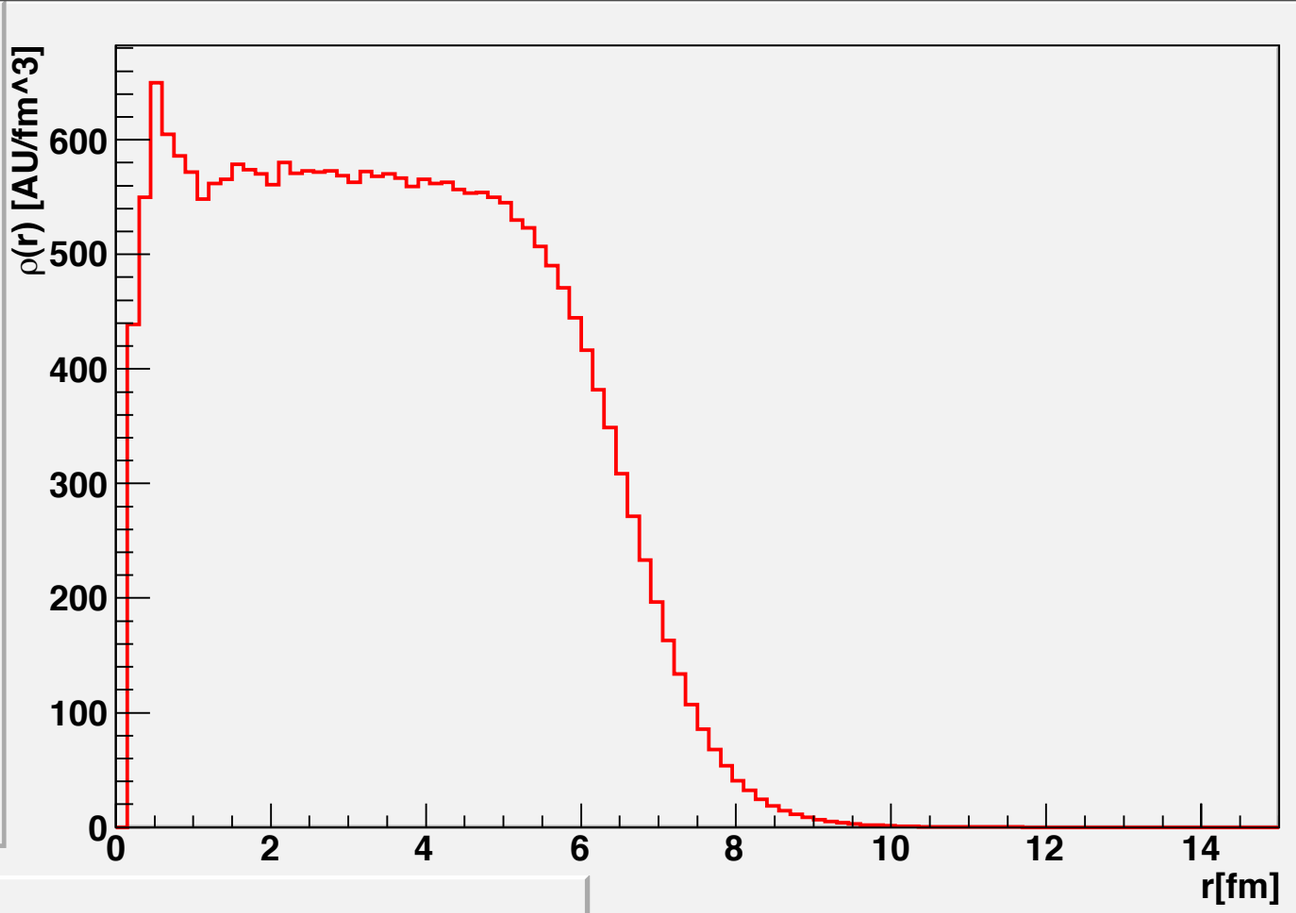
Check if the new nucleon is within a core-distance from any previous nucleon

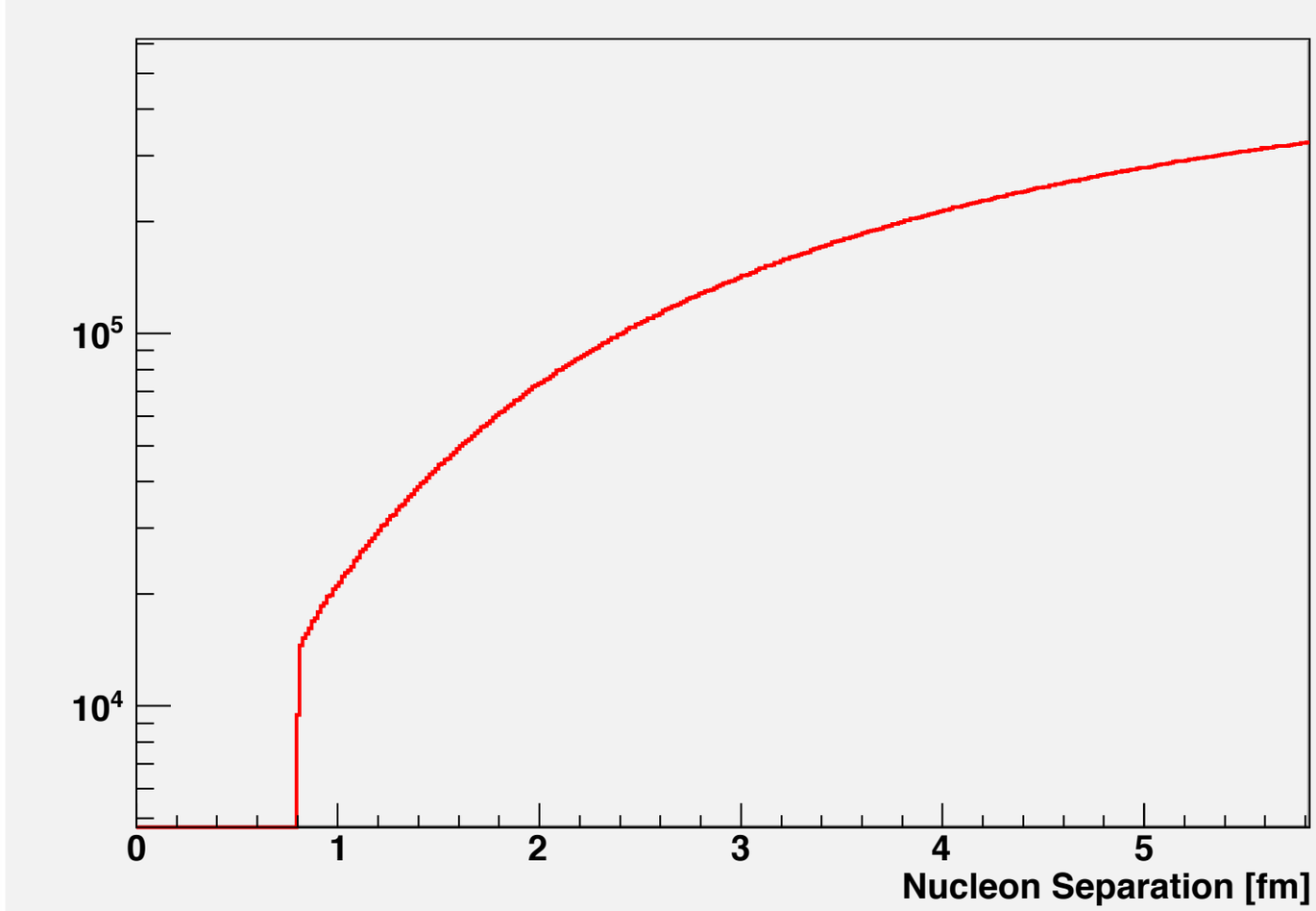
If not -> keep it

else -> regenerate angles

If this fails 1000 times discard nucleus and restart


[AU]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
2
4
6
8
10
12
14
Radius [fm]


ρ(r) [AU/fm^3]
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
r[fm]


10^5
10^4
0
1
2
3
4
5
Nucleon Separation [fm]

Technical Problems!

MC has the same cross-section formula all the time.

Our's fluctuate event by event!!!

This makes the code unreliable in present form...

Technical Problems!

MC has the same cross-section formula all the time.

Our's fluctuate event by event!!!

This makes the code unreliable in present form...

nucleus #	rho cross-section	j/psi cross section
1	9020.225804638240	1224.251854397390
2	9121.111637252360	1158.990897781200
3	9196.210773654010	1127.206952442990
4	8871.020004394170	1156.314391203930
5	9207.502618556510	1157.482694319310
6	8924.520804975000	1235.28828006791
7	9236.943000895560	1185.627428172140
8	8980.411710585330	1176.667559345780
9	9302.28426421595	1207.730165816750
10	9019.48693863964	1125.247843117940
Mean	**9087.97175578068**	**1175.48080666653**
RMS	**137.788595**	**35.9400177**

1.5%

3.1%

Technical Problems!

MC has the same cross-section formula all the time.
Our's fluctuate event by event!!!
This makes the code unreliable in present form...

At the moment:
Use same nucleus for all events
Does not affect total cross-section much
but has effect on shapes in distributions.

Other Solutions?
Weighted events (with unweighting procedure)??

Technical Problems!

$$\frac{\mathrm{d}\sigma^{(A)}{}_{q\bar{q}}(r,x,\mathbf{b})}{\mathrm{d}^2\mathbf{b}} = 2\left[1-\prod_{i=1}^{A}\left(1-\frac{1}{2}\frac{\mathrm{d}\sigma^{(p)}{}_{q\bar{q}}(r,x,|\mathbf{b}-\mathbf{b}_i|)}{\mathrm{d}^2\mathbf{b}}\right)\right]$$

Extremely slow!!!!

bSat:

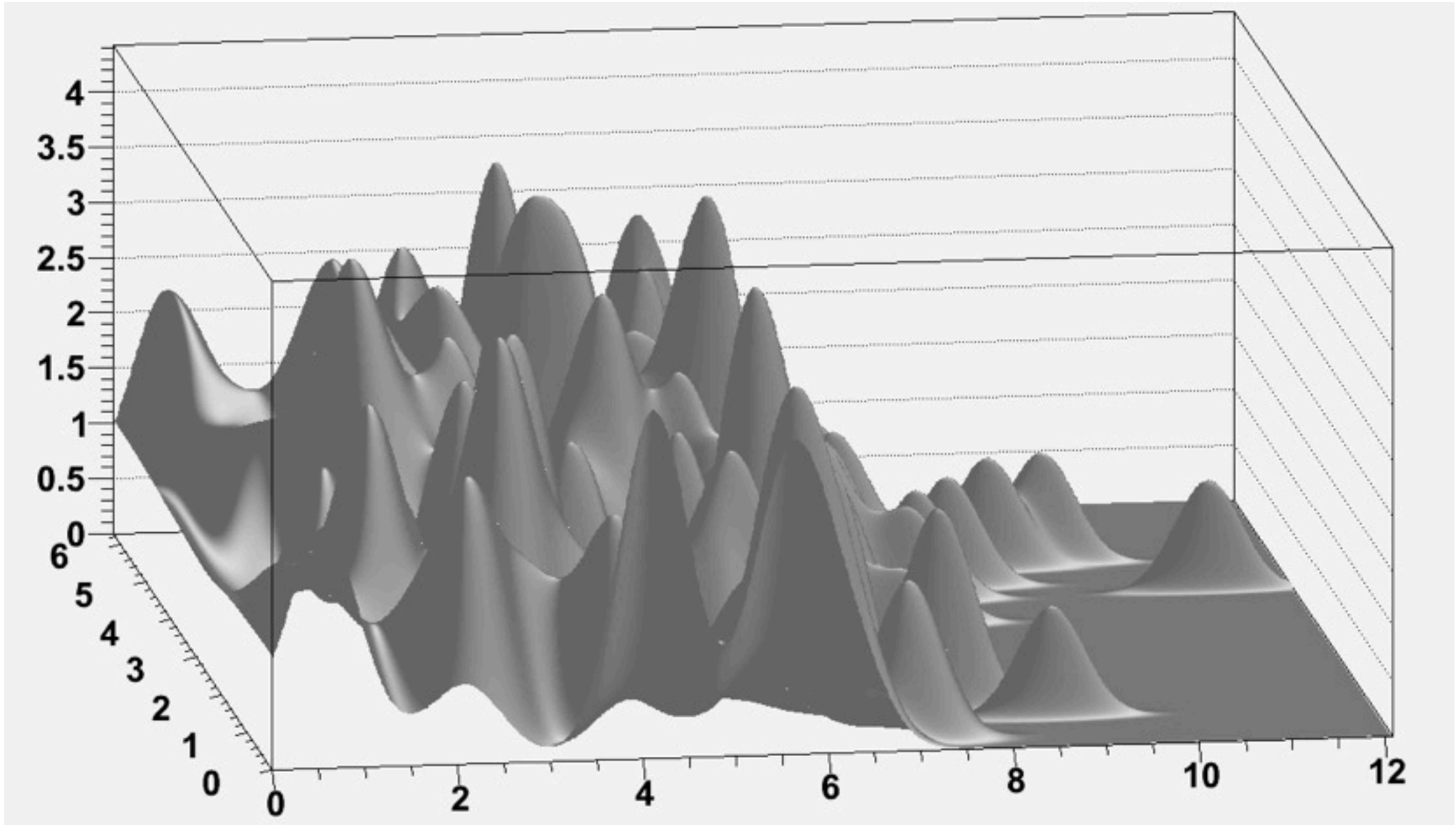
$$\frac{\mathrm{d}\sigma^{A}_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1-\exp\left(-\frac{\pi^2}{2N_c}r^2\alpha_{\mathrm{s}}(\mu^2)xg(x,\mu^2)\sum_{i=1}^{A}T_p(\mathbf{b}-\mathbf{b}_i)\right)\right]$$

Product becomes a sum over a function only dependent on b.

Not possible for bCGC!!

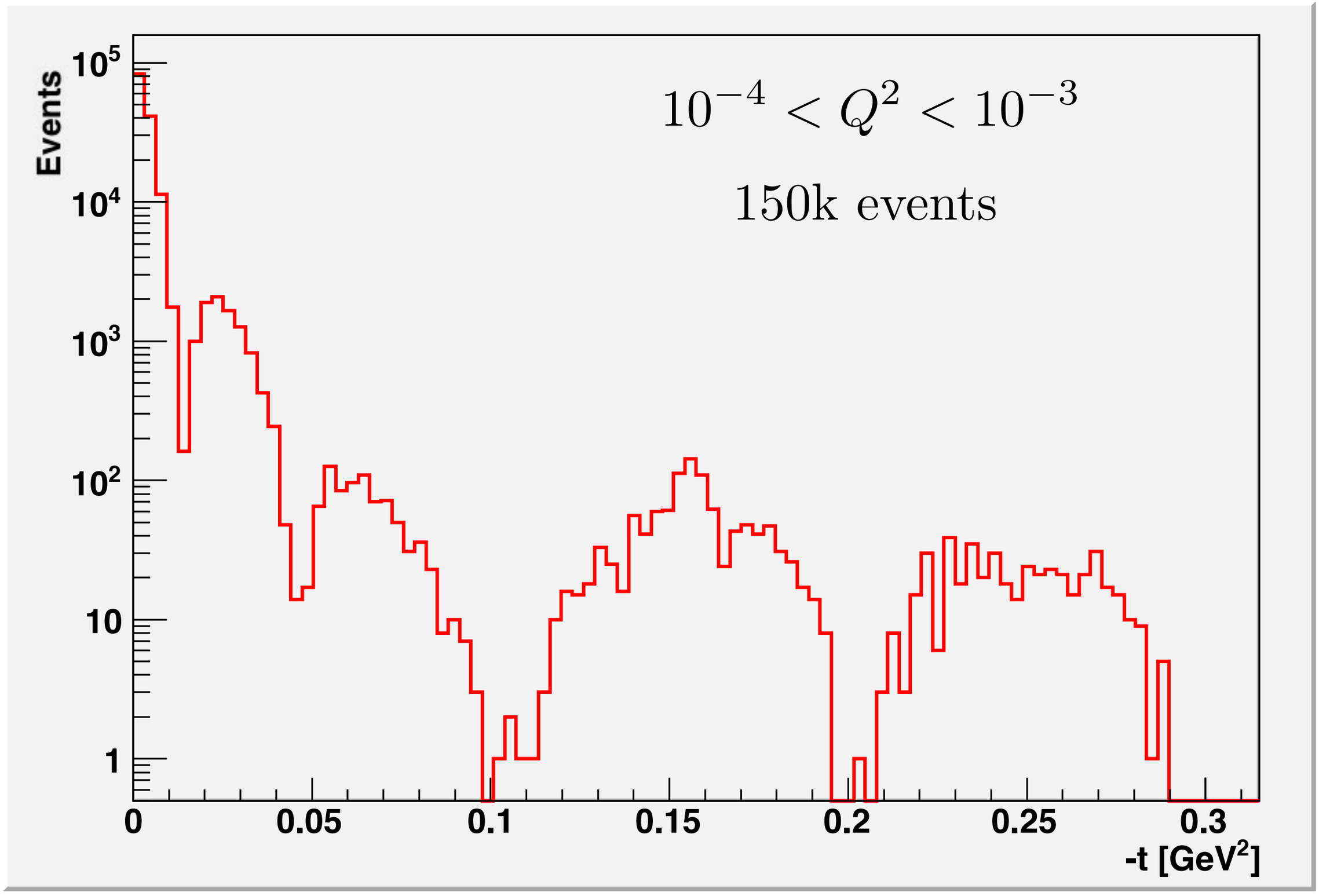
Technical Problems!

To speed things up for bSat a look-up table is created for the b-dependence at the beginning of the run:

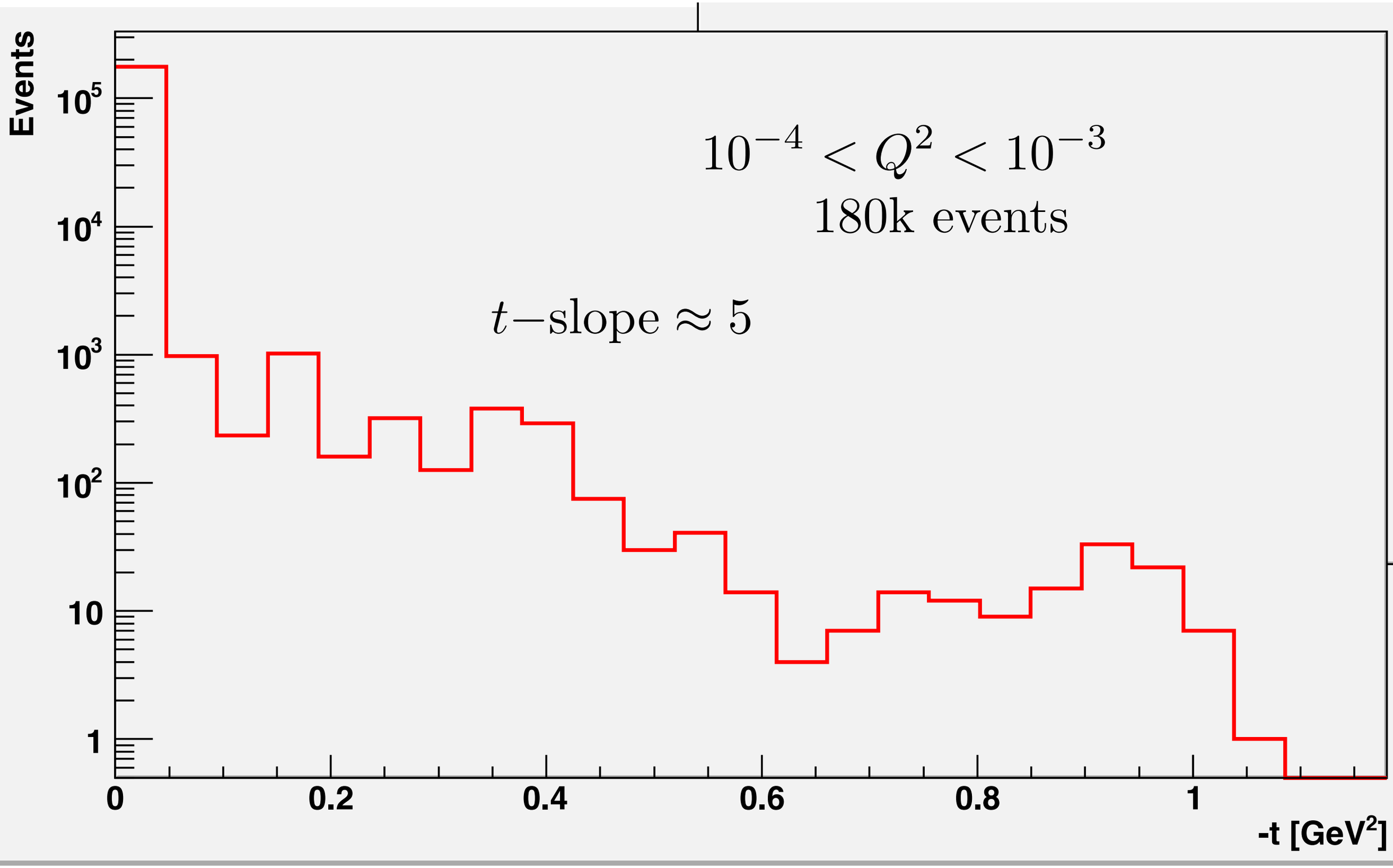


Results

Results


Events
10^5
10^4
10^3
10^2
10
1
0
0.05
0.1
0.15
0.2
0.25
0.3
-t [GeV^2]
$10^{-4} < Q^2 < 10^{-3}$
150k events

Results


Events
10^5
10^4
10^3
10^2
10
1
0
0.2
0.4
0.6
0.8
1
-t [GeV^2]
$10^{-4} < Q^2 < 10^{-3}$
180k events
$t-$slope ≈ 5

To Do

DVCS has been implemented
(no BH yet)

Open Questions (at the moment)

How to average over the nuclei correctly?

How to distinguish between incoherent and coherent part? Break-up of the nucleus?

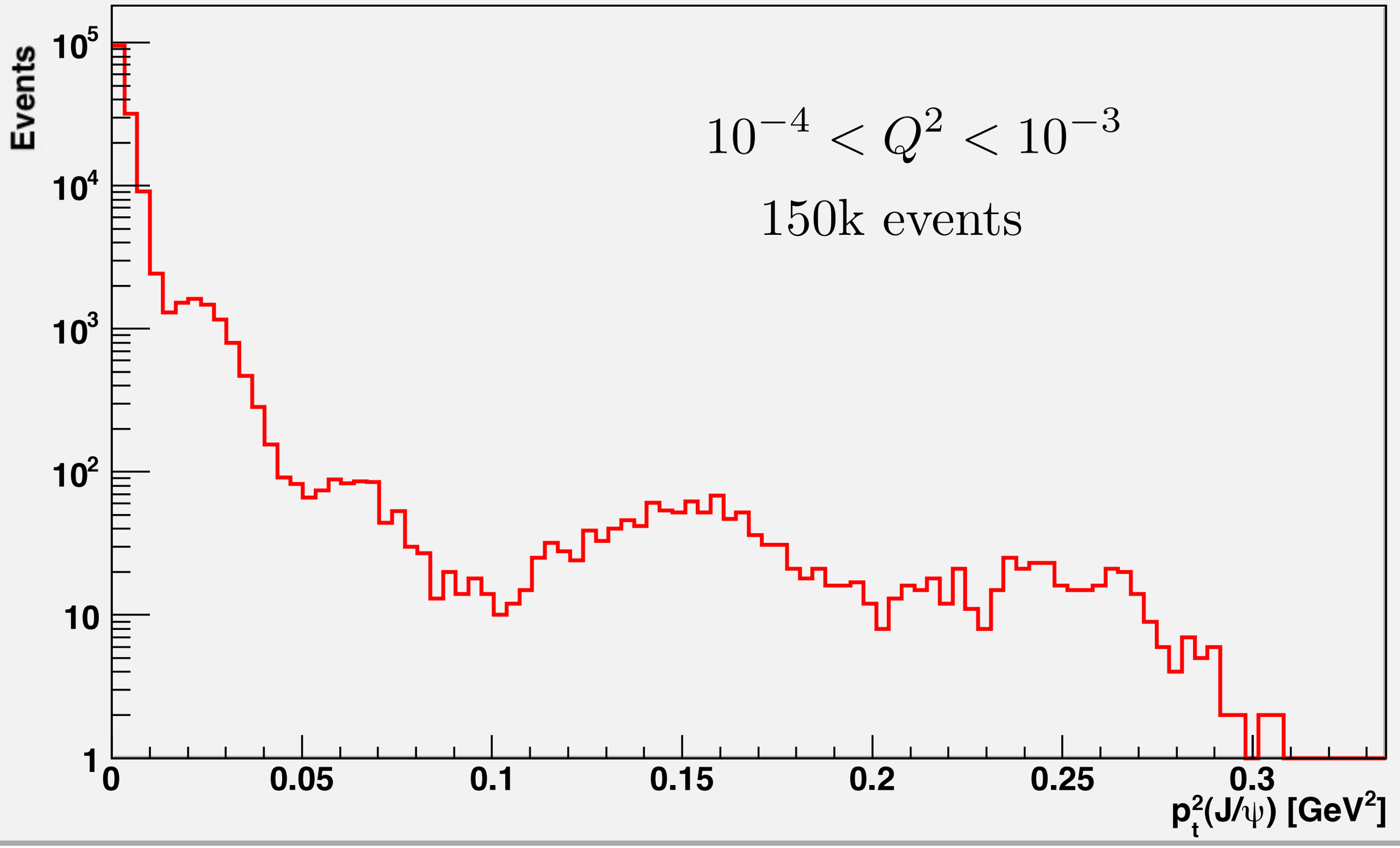
Generalize eA→e'A'V to eA→e'A'X

What has been done

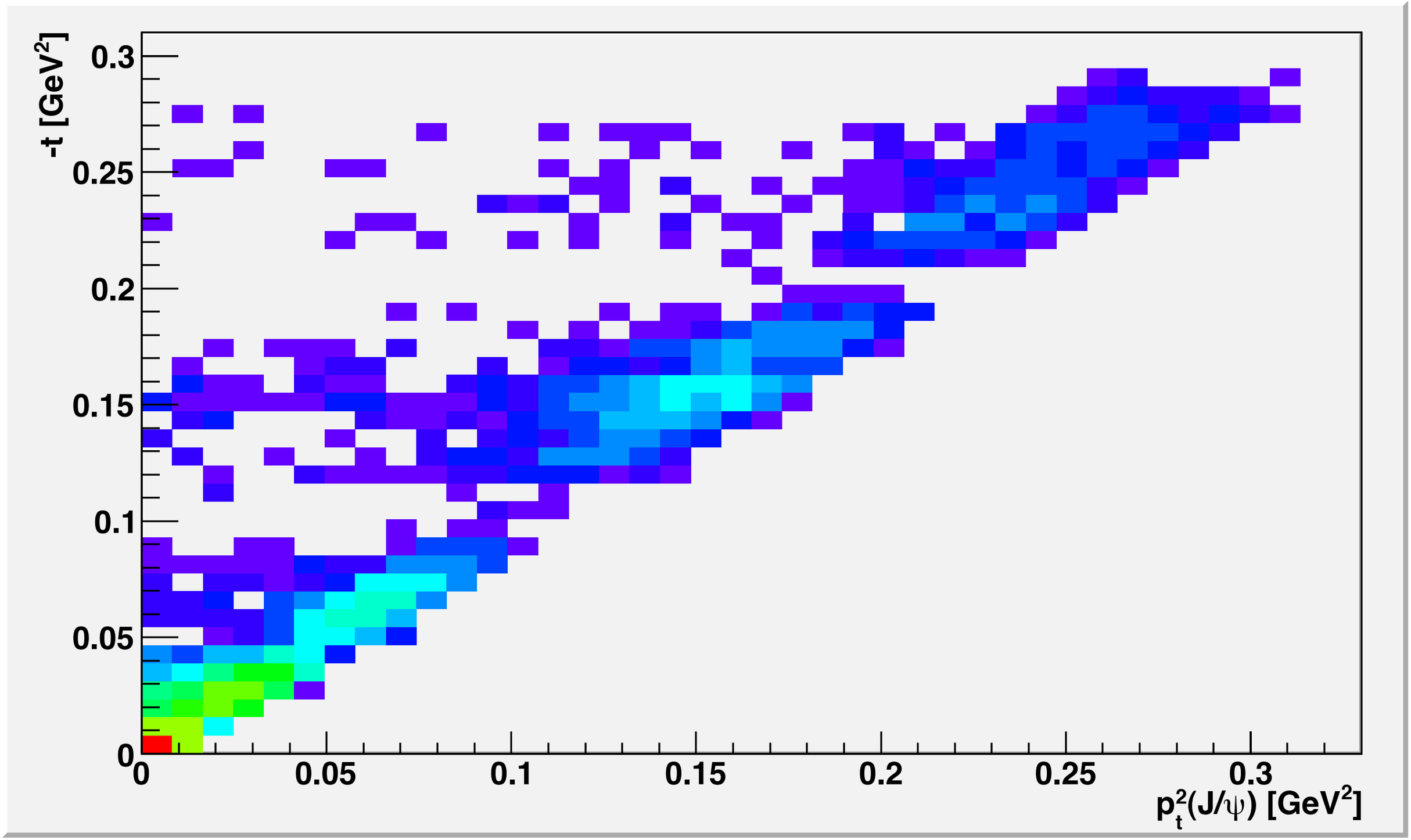
- Real part of Amplitude corrections (done)
- Skewedness Corrections (done)
- Nucleus Generation and Implementation (ongoing)
- DVCS amplitude (ongoing/todo)

Back Up

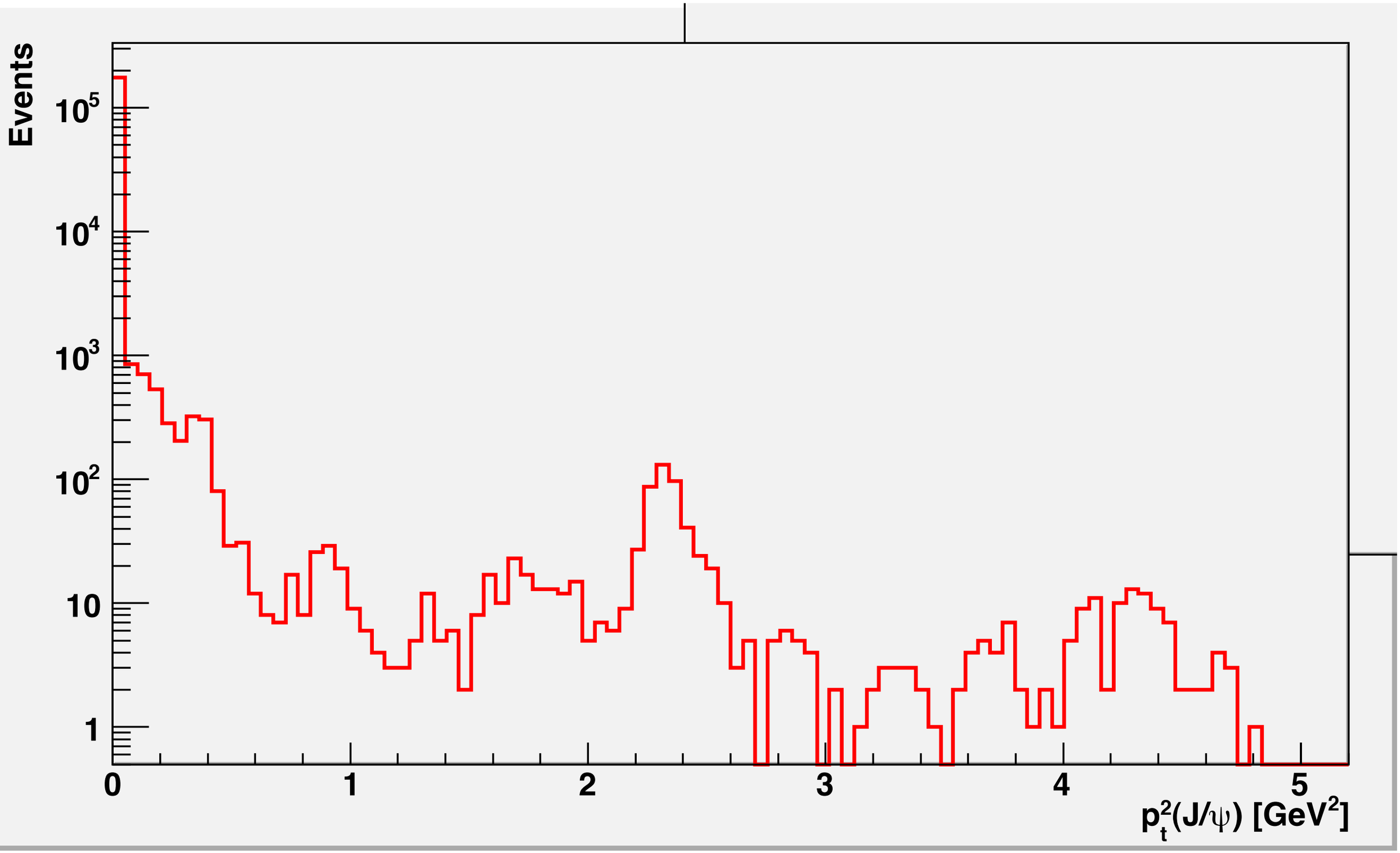
Results


Events
10^5
10^4
10^3
10^2
10
1
0
0.05
0.1
0.15
0.2
0.25
0.3
$p_t^2(J/\psi)$ [GeV^2]
$10^{-4} < Q^2 < 10^{-3}$
150k events

Results



Results



Results